Development of Eastern White Pine (*Pinus strobus* L.) Regeneration under a Reserve Shelterwood after Intermediate Removals and Windthrow

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ABSTRACT

We followed the growth response of naturally regenerated 12-year-old white pine for 4 years after a shelterwood removal cut in a mixed red and white pine stand having an overstory that was significantly reduced by windthrow at the beginning of our study. Postrelease overstory density was reduced to levels (4.5 m^2 ha) that did not significantly influence any regeneration growth parameter while understory woody competitors taller than sample trees negatively influenced growth. Analyses revealed differential response to release based on prerelease growth rates with slower-growing trees responding fastest. Release shock persisted for the fastest prerelease growers up to 4 years after harvest.

Keywords: white pine, advance regeneration, shelterwood, release cut, release shock

White pine (*Pinus strobus* L.)–red pine (*Pinus resinosa* Ait.) stands cover over 1.3 million ha in Ontario, while in the western Great Lakes forests of Minnesota, Wisconsin, and Michigan white pine–dominated stands occupy nearly 300,000 ha (Watkins 2002, Miles 2004). The economic value of wood products, importance of the ecological role, and social significance associated with white pine continues to generate a great deal of interest among foresters and the public throughout the Great Lakes region (Wood and Dewhurst 1998, Watkins 2002). Societal pressures also are increasing on forestry professionals to use silvicultural methods that yield structurally diverse stands and take advantage of natural regeneration opportunities (Watkins 2002).

Taking advantage of white pine's intermediate shade tolerance, the two- or three-cut shelterwood harvest method has been a common silvicultural prescription for regenerating the species for nearly 100 years (Frothingham 1914, Hannah 1988, Puettmann and Ek 1999). In the Lake States, the typical shelterwood application prescribes the complete removal of remaining overstory trees once regeneration is established (Hannah 1988). In contrast, the staggered removal of overstory trees in several partial removal cuts is designed to promote the establishment of regeneration and some degree of protection from damage agents such as blister rust (*Cronartium ribicola* Fisher) and white pine weevil (*Pissodes strobi* Peck; Katovich and Mielke [1993]). In a shelterwood with reserves method, a portion of the overstory is retained and the removal period is extended to create irregular stand structures for purposes of weevil protection and improved form class, aesthetics, or wildlife habitat (Pubanz 1995, Burgess et al. 2002, Bebber et al. 2004). This method relies on the assumption that the regeneration can respond quickly to release and the density of the retained overstory minimally impacts growth. In this manner, the prerelease growth patterns in white pine provide good indications for postharvest growth responses in sapling size regeneration (Kelty and Entcheva 1993, Puettmann and Saunders 2000) but little information about smaller growth stages exists.

The shelterwood with reserves method is not commonly used in the Lake States and it is uncertain to what extent retaining overstory trees beyond the point when the regeneration is well established reduces growth and development of the new cohort (Puettmann and Ek 1999). This study aims to fill this knowledge gap. We report on the effects of 110-year-old red pine–white pine residual overstory trees on the growth response on a 12-year-old cohort of white pine advanced regeneration after a shelterwood release cut in 1998 with reserves that was further modified by the 1999 July 4th blowdown event that impacted large areas of northern Minnesota.

Study Area

Our study was conducted 29 km east of Orr, Minnesota in northwestern St. Louis County (approximately 48°03′ N, 92°25′ W; altitude, approximately 400 m above sea level) and occupied 10 ha of a 26-ha management unit located on the La Croix Ranger District of the Superior National Forest. The site is gently sloping (slopes less than 8%) with a north aspect and scattered shallow depressions with bedrock escarpments with a designated Ecological Land Type of 16 (US Forest Service: upland shallow loamy dry; Strand [1997]). Soils are uniformly shallow (50–100 cm), coarse, loamy soils over granite bedrock (Strand 1997). A macronutrient analysis was conducted at a central location at depths of 0–15 cm and 16–30 cm (Table 1). The red pine site index (50-year) is 18 m. The climate is midcontinental, with mean January temperatures of −15° C and a mean July temperature of 19° C. Mean cumulative

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Table 1. Results of soil macronutrient analysis.

Depth	pH	Bray-P	K	Ca	Mg	Na	NO_3N
0–15 cm	4.3	31	82	251	34	37	0.6
16–30 cm	4.8	19	66	67	14	32	0.5

growing season (April to August) precipitation is 40 cm (Cook Meteorological Station, Minnesota State Climatology Service).

Stand History

Soil scarification resulting from a shelterwood harvest in 1983 coupled with good seed crops resulted in 90% stand occupation with mean white pine regeneration stocking densities of 4,100 stems/ha (range, 2,500–8,350) by 1997 (Strand 1997). A regeneration survey conducted before the 1998 release cut indicated that white pine comprised 85% of the advance regeneration and ranged in height from 0.3 to 6 m with the remainder being almost exclusively red pine (Strand 1997).

In 1998 the overstory consisted of 110-year-old (60- to 130-year range) red and white pine (Strand 1997). Overstory basal area (BA) averaged 25 m^2/ha (range, 14–30 m^2/ha) and the stand had an estimated crown closure of 60%. Red pine comprised approximately 80% of BA and white pine comprised approximately 20% of BA, with scattered sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britton), quaking aspen (*Populus tremuloides* Michx.), white spruce (*Picea glauca* [Moench] Voss), and balsam fir (*Abies balsamea* [L.] Mill). In the winter of 1998, another removal cut reduced overstory BA using a mechanical harvester and full tree skidding to a central landing. On July 4, 1999 northern Minnesota experienced an extreme thunderstorm event that resulted in widespread windthrow across the region. This windthrow event further reduced residual overstory densities by approximately 50%, resulting in a mean BA of 7.9 m^2/ha ($\pm$3.7 m^2/ha).

Overstory BA, height, and dbh were sampled in 1999 after the windthrow event. The red pine overstory averaged 23 m ($\pm$4 m; note, mean $\pm$ SD) in height, with an average dbh of 35 cm ($\pm$9 cm). The white pine overstory averaged 23 m ($\pm$5 m) in height and 38-cm dbh ($\pm$10 cm). Between 1999 and 2003 windthrow further reduced BA to 4.5 m^2/ha ($\pm$2.3 m^2/ha).

Study Design

We systematically selected 120 visibly healthy white pine trees along a transect to capture the range of conditions present for advance regeneration. The mean age of trees selected for this study was 12 years ($\pm$3 years) as determined by whorl count. Measurements included height, basal diameter (basal diameter at 5 cm), dbh, and live crown length. Prerelease height growth for the last 4 years was determined by measuring height to corresponding branch whorls. Competing advance regeneration trees were tallied in a 1-m radius around each sample tree. In a similar manner, competing herbaceous ground cover (%) was visually estimated in a 1-m radius around each sample tree. One-half of the sample trees were systematically selected across the full range of heights for pathological pruning. Between 20 and 45% of the lower live crown was removed with pruning shears. Pathological pruning was included as a part of a broader assessment of the merits and impact on juvenile white pine conducted in northern Minnesota. Except for the obvious impact on live crown ratio, pruning was not found to significantly impact growth and is not discussed further here (see Zenner et al. [2005]).

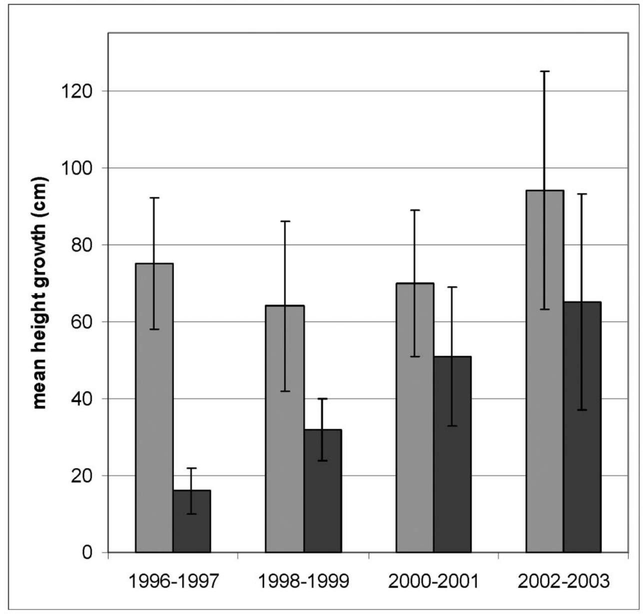

Figure 1. Illustration of the differential pre- and postrelease height growth of the fastest (25% of trees) and slowest (25% of trees) growing trees. Trees are grouped based on 2-year prerelease (1996–97) height growth rates. To illustrate the postrelease shock and subsequent recovery, postrelease height growth is presented in three separate growth periods. Bars represent mean; error bars are $\pm$SD. Slowest prerelease growers are dark bars; fastest prerelease growers are light bars.

Statistical Analysis

SAS Version 8, (SAS Institute, Inc., Cary, North Carolina) was used to construct and test statistical models. All tests were considered significant if $P \leq 0.05$. Multiple linear regression models were constructed to evaluate the effects of residual overstory BA; 2-year prerelease growth; number of understory trees that were taller, shorter, or of same height; and herbaceous ground cover on measures of tree growth (height, dbh, and basal diameter growth). In addition, using summary statistics (mean $\pm$ SD) to examine the general influence of release, we grouped the trees into quartiles based on their height growth rate in the 2 years before release (1996–97) and for purposes of illustration report the results for the slowest- and fastest-growing groups (1998–2003) after release (Figure 1). In addition, we report summary statistics to illustrate overall height, dbh, and basal diameter growth responses. Two-tailed *t*-tests were used to compare the significance of pre- and postrelease growth responses among groups reported. Note that references to year of analyses are inclusive for those years' growth.

Results

Overstory Influence

The significant reduction in white and red pine overstory density that occurred as a function of harvest operation and windthrow resulted in a relatively open stand. The low density levels resulted in essentially "free to grow" conditions for the advance regeneration

Table 2. Results of regression model analysis for height, dbh, and basal diameter growth.

Model/source	Coefficient value	df	MS	F	Pr > F
Δ Height growth 2000–2003 model (r^2 = 0.2)		3	14,076	8.57	<0.0001
Δ Height growth 1998–1999	2.4	1	17,539	10.7	0.002
Δ Height growth 1998–1999*Δ height growth 1998–1999	−0.02	1	8,362	5.09	0.03
Overstory BA	−1.5	1	1,062	0.65	0.4
Δ dbh Growth 2000–2003 model (r^2 = 0.37)					
Δ Height growth 1998–1999	0.16	1	627	13	0.0006
Overstory BA	0.38	1	45	0.95	0.3
Taller understory competition	−2.4	1	541	11.4	0.001
Δ Basal diameter growth 2000–2003 model (r^2 = 0.27)		3	479	8.3	<0.0001
Basal diameter 1999	0.14	1	221	3.8	0.06
Overstory BA	0.04	1	0.57	0.01	0.9
Taller understory competition	−2.5	1	697	12	0.0009

Taller understory competition refers to the number of trees within 1 m from target trees that were taller than target trees.

white pine. Within the range of overstory BA created in this study (0–9 m^2/ha), regression analyses indicated no significant influence of overstory density on height or radial growth (all values of $P > 0.3$; Table 2).

Height Growth

In the growing seasons after the release cut, the average height of advance white pine regeneration increased from 191 cm (±98 cm) in 1998 to 368 cm (±134 cm) in 2003. However, the height growth response to release appears dependent on prerelease height growth patterns and regression analysis indicated that the relationship between pre- and postrelease height growth was curvilinear (i.e., both prerelease height growth and squared prerelease height growth were significant). The model shows that postrelease height growth increased for trees that grew up to 75 cm in height 2 years before release. Trees in which their prerelease height growth exceeded 75 cm experienced release shock and grew at a slightly slower rate. Similar results were obtained when comparing trees that belonged to the upper 25% and lower 25% of the prerelease height growth distribution. Although slower-growing trees still grew at a lower rate than fast-growing trees, slower-growing trees responded immediately to release and doubled their height growth increment from 16 cm in 1996–97 to 32 cm in the 2 years after release ($P \leq 0.0001$). The positive increases ingrowth response pattern held for this group and growth continued to increase through 2003. In contrast, the 25% fastest-growing trees exhibited a suppressed height growth response for 4 years after release, decreasing by 15% in the first 2 years after release. Four years after release, height growth in this group had recovered and exceeded prerelease height growth in the final 2 years of the study by 35% (Figure 1).

dbh and Basal Diameter Growth

Both dbh and basal diameter growth were positively and linearly related to prerelease height growth; i.e., trees that grew faster before release exhibited greater radial growth than trees with slower height growth. As with height growth, summary statistics indicate the largest dbh growth increment occurred in the final 2 years of the study, averaging 10.8 mm (±13 mm) over the 2-year period. Mean basal diameter increased from 32 mm (±18 mm) in 1998 to 49 mm (±24 mm) in 2003. The dbh also exhibited rapid growth and increased from a mean of 17 mm (±12 mm) in 1998 to 40 mm (±25 mm) in 2003.

Regression models examining the influence of competition from understory tree competitors revealed no significant influence on height growth. However, there was a significant negative influence from taller understory trees (white and red pine) on both dbh and basal diameter growth but not height growth (Table 2). For example, the mean impact from the addition of a single taller competitor within 1 m decreased dbh growth by 2.4 mm and basal diameter growth by 2.5 mm (2000–2003 growing seasons). The average number of understory competitor trees (white and red pine) was four, of which one was a taller competitor. Competitors of the same height or shorter were not found to significantly influence growth. Our analysis also indicates that herbaceous ground cover had no significant impact on growth responses of advance white pine regeneration.

Discussion

The combination of removal cut and windthrow reduced residual overstory density levels below levels that restricted the growth response for the established white pine regeneration. Clearly, the BA reduction in our study resulted in a shelterwood stand structure outside the norm in northern forests (Hannah 1988). With an overstory density below 9 m^2/ha, light saturation conditions for white pine regeneration were likely reached in our study (Logan 1966, Wetzel and Burgess 2001). For younger white pine, studies indicate a robust height growth response where crown separation is as little as one crown width and peaks around 50% of full light conditions (Logan 1966, Wetzel and Burgess 2001). The lack of impact on growth from low overstory density levels in this coniferous stand provides a benchmark for managers looking to promote growth and retain structural diversity after a removal harvest.

Somewhat similar to the findings of Puettmann and Saunders (2000), who examined the release response of 33- to 40-year-old advanced white pine regeneration under a northern hardwoods overstory, we recorded a differential growth response to release based on preharvest height growth rates. Although Puettmann and Saunders (2000) did not observe a differential response of the fastest quartile prerelease growers, their study revealed a short-duration release shock that was correlated to prerelease growth rates. In this study, results indicate that the "release shock" for those trees that were the fastest prerelease growers persisted for up to 4 years. Recovery remained steady during this time and by the final 2 years this group had recovered and height growth exceeded levels observed before release (Figure 1). The slowest prerelease growers (bottom quartile), in which their 1996–97 height growth increment was only 20% that of the fastest prerelease growers, showed a vigorous, immediate response to overstory release. In the final 2 years of the study, this group's height growth increment had increased to 70% of the fastest prerelease growers.

The release shock observed in our study is similar to the 2- to 3-year suppressed response observed in overstory release studies in lodgepole pine (*Pinus contorta* Dougl. Ex Loud.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.; Kneeshaw et al. [2002] and Krasowski and Wang [2003]). Given the lack of significance associated with the common metrics collected in this silvicultural study (i.e., overstory density and understory competitors), other factors appear to be driving the early growth response (release shock) in conifer shelterwood harvests. After release, significant changes to a range of microclimatic factors, local competition, and nutrient availability alter the investment in carbon allocation and likely play a significant role in the intensity of release shock (Parker 2002, Krasowski and Wang 2003).

Although competition from taller understory trees negatively affected diameter growth, the lack of a significant negative impact from other components of understory competition differs from other competition studies (Meiners and Handel 2000, Krueger and Puettmann 2004). The sensitivity of diameter growth in juvenile white pine to competing vegetation is well established, even when height growth responds vigorously (Bormann 1965, Brand 1990, Saunders and Puettmann 1999). The consequence of high stocking levels in the regenerating cohort, especially of nondesirable taller competitors (Wagner and Radosevich 1998), may significantly lower diameter growth to the point that stocking controls may be required. A key difference between our study and others was that on this site there was a near absence of a robust woody shrub and shade-tolerant midstory tree layer (Smidt and Puettmann 1998), with dominant understory competition consisting primarily of same species trees and grasses.

Silvicultural Implications

In this study, vigorously growing established white pine regeneration responded well to release with no significant impact from retained overstory densities as high as 9 m^2/ha. It appears that social and biological benefits associated with structural diversity obtained through retention harvests can be realized in white pine stands with little impact on growth of the next cohort, at least in the short-term. Although we observed a differential height growth response after release, under essentially free to grow conditions, even those advanced regeneration white pines most affected by release shock recovered within 2–4 years. In addition, in the absence of a highly competitive, shade-tolerant midstory, older advanced regeneration competes well with trees of equal or lesser height but loses diameter growth when subjected to suppression from taller competitors in the understory. Managers need to recognize the impact of understory competitor stocking levels on diameter growth and may need to enter stands to control density levels where diameter growth is an important objective. Low-density shelterwood operations in white pine stands can be a viable method for promoting regeneration and achieving good growth rates (height and diameter) in the future stand. Social benefits and structural diversity goals are likewise achieved. As the stand dynamics change, managers will need to consider further adjusting stocking levels in both the understory and the residual overstory to maintain desired silvicultural and social benefits.

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